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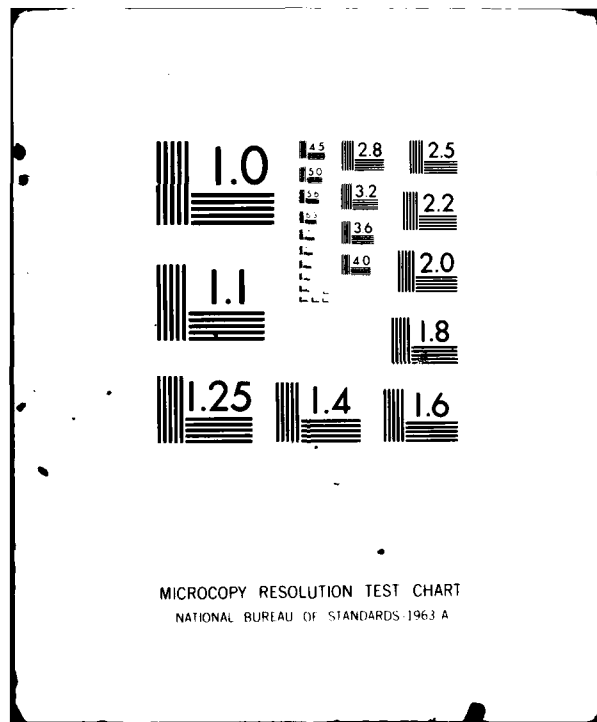
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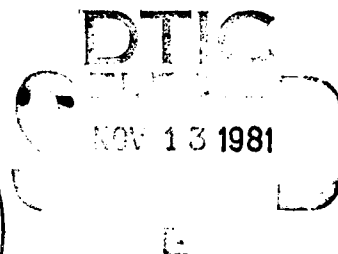
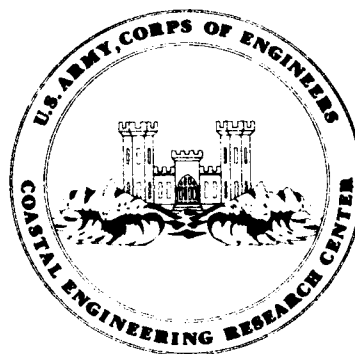
Fast, Accurate Two-Person Beach Surveys

by

William A. Birkemeier

COASTAL ENGINEERING TECHNICAL AID NO. 81-11

AUGUST 1981



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to obtain accurate distances. The Emery method uses two 5-foot calibrated rods and the horizon to measure distances to, and changes in elevation between, two survey points. Errors are additive and large elevation errors are possible particularly on wide beaches.)

(This report discusses a modified stadia surveying procedure which, when used properly, is fast and produces data of comparable accuracy to level and tape surveying. Because more readings are taken (three per survey point), the data provide a higher degree of confidence than is available with the other methods. The modifications include the addition of two stakes to the profile line monumentation, pacing the distance between each point, and performing a simple mental field check of data quality. Using the stadia method, a typical profile of 10 to 15 survey points can be surveyed in 15 to 20 minutes including instrument setup time.



PREFACE


This report describes a useful method for two-person beach surveying. Although the method does produce data of comparable accuracy, it is not intended to replace traditional level and tape surveying using three or more surveyors. The method was developed and field tested during 3 years of studying winter storm effects. The work was carried out under the coastal processes program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by William A. Birkemeier, Hydraulic Engineer, under the supervision of C. Mason, Chief, Field Research Facility Group, Research Division.

The author acknowledges the assistance of many CERC staff members, particularly Dr. C. Galvin, formerly Chief, Coastal Processes Branch, who contributed greatly in refining and field testing the method; M.W. Leffler, who participated in many surveys using the procedures and made numerous helpful comments; and A.E. DeWall, R.A. Jachowski, and C. Mason for their review and comments.

Comments on this publication are invited.

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TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins ¹

¹To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9) (F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9) (F - 32) + 273.15$.

FAST, ACCURATE TWO-PERSON BEACH SURVEYS

by

William A. Birkemeier

I. INTRODUCTION

The most desirable method of beach surveying is to use a surveying level to determine elevation and a tape to measure distance; however, the procedure requires a minimum of three people for an efficient survey. Two popular surveying methods, which require only two people, are stadia surveying and Emery surveying. The Emery method (Emery, 1961)¹ uses the horizon to establish a level line and two 5-foot (1.5 meters) calibrated poles to measure both the distance and the change in elevation between successive survey points. Since the accuracy of each point is dependent on the accuracy of preceding points, large errors are possible (Czerniak, 1973)². Emery's method also requires that survey points be taken every 5 feet, a severe restriction on long, flat beaches. For these reasons, the Emery method is not recommended.

In a stadia survey (Davis, Foote, and Kelly, 1968)³, the elevation and distance to each point are determined by three readings of the surveyor's rod using a surveying level located on the profile line. The readings are taken from three crosshairs visible through the level's eyepiece: the center crosshair is used for elevation, and the two outside (top and bottom) crosshairs are used to determine distance. Advantages are speed and the fact that each survey point is independently determined. The primary disadvantage is that distance along the profile line is indirectly measured.

This report discusses a modified stadia surveying procedure commonly known as three-wire leveling which overcomes this disadvantage, and which has proven to be fast, economical, and sufficiently accurate for this type of surveying. These procedures are not intended to replace traditional level and tape surveying. They are an improvement over the Emery method and can be useful whenever only two people are available or when a quick survey is required (e.g., during poststorm damage assessments). While professional surveyors will find that much of the material is a review, the report does provide some useful insight into the problems of beach surveying. These procedures have been developed during 3 years of extensive beach surveys before and after storms where speed and accuracy were essential.

¹EMERY, K.O., "A Simple Method of Measuring Beach Profile," *Limnology and Oceanography*, Vol. 6, No. 1, 1961, pp. 90-93.

²CZERNIAK, M.T., "Comparative Field Test of Three Beach Profile Survey Methods," Memorandum for Record, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Aug. 1973.

³DAVIS, R.E., FOOTE, F.S., and KELLY, J.W., *Surveying Theory and Practice*, McGraw Hill, Inc., New York, 1968.

II. EQUIPMENT

The following basic equipment is required for the stadia survey:

Automatic level and tripod	Leveling format fieldbook
Circular rod level	Safety line (100 to 200 feet or 30 to 61 meters)
Fiberglass level rod (25 to 30 feet or 7.6 to 9.1 meters)	Surveying tape and pins
Flotation jacket	Two range poles
Level rod foot	Waders or dry suit

The use of an automatic level is recommended; it sets up faster and is less susceptible to movement than either a transit or a dumpy level. A high-powered telescope (X30 or greater) is also recommended to improve the ease and accuracy of long shots. The telescoping fiberglass level rod is unaffected by saltwater and is long enough to survey most beaches without turning points. The level rod must be used with a circular rod level to ensure that it is held vertically; however, because of bending, use of the top sections in high winds is not recommended. To reduce scour under the rod in the surf zone, a foot (similar to the Plexiglas, 7-inch-diameter foot shown in Fig. 1) should be added to the bottom.



Figure 1. Plexiglas level rod foot.

There are several ways to protect the rod person during cold-water surveying. The most effective protection (also the most expensive) is a skin diver's dry suit worn over clothing; however, in hot weather the suit becomes too warm. A wet suit may be substituted, but it also becomes uncomfortable during a full day of surveying. A pair of waders worn under a flotation jacket (Fig. 2) provides adequate comfort and emergency buoyancy. High surf conditions should be avoided and a safety line kept handy for emergencies.



Figure 2. Rod person wearing waders and flotation jacket.

III. MONUMENTATION

Since survey distances are measured relative to the location of the instrument, its position on the profile line must be accurately determined. Each profile line should be located by a permanent survey monument made from a concrete cylinder or deep-driven steel pipe. The elevation of this monument should be established since it will serve as the bench mark (BM) for each survey of the profile line. The monument also serves as the start of the profile line with all distances measured from it.

To accurately determine the instrument location, the distance from the instrument to the survey monument should be tape measured. This is not always practical if the monument is located a distance from the beach. Since this is often the case, some additional monumentation along each line to be surveyed (assuming repetitive surveys are planned) is required. Figure 3 shows a typical profile line (see Hemsley, in preparation, 1981, for details on establishing primary monuments)⁴. A 3-foot (1 meter) wood or pipe temporary bench mark (TBM) is set online and near the best possible instrument location (in a stable part of the profile near the beach). The elevation and location of the TBM are accurately determined from the profile monument. The distance from the profile monument to the TBM should be taped.

⁴HEMSLEY, M.J., "Guidelines for Establishing Coastal Survey Base Lines," U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va. (in preparation, 1981).

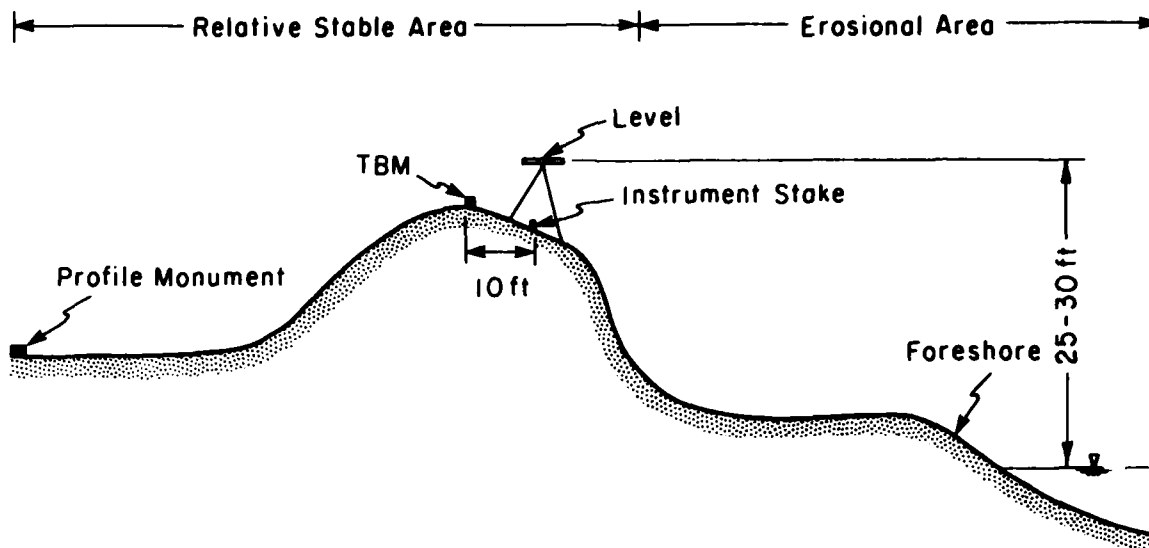


Figure 3. Schematic of profile line showing relative location of TBM and instrument stake.

A second wooden stake 1.5 feet (0.5 meter) long should be placed online and 10 feet (3 meters) seaward of the TBM. This stake is used during each survey to locate the instrument online and in approximately the same place. The ground elevation of this point should be at least 5 feet less than the maximum length of the level rod to allow the profile to be surveyed to the elevation datum without requiring turning points. During each survey, the actual instrument height and location are determined from direct measurement to the TBM using the level rod as a tape to measure the distance. Thus, only direct measurements (no stadia) are used to locate the instrument. These two stakes have the added benefit of indicating profile azimuth.

For consistency and ease of later analysis, each survey should begin at the same point and cover a part of the profile that will remain stable during the life of the study. Additionally, one survey (preferably the first one) should extend sufficiently landward to provide a reference profile in the event of erosion reaching the TBM.

IV. SURVEY PROCEDURE

The survey crew includes a rod person (RP) and an instrument person (IP). The RP is responsible for holding the level rod and for selecting the points to be surveyed. The IP makes the measurements and records the data.

1. Instrument.

The IP positions the instrument over the instrument stake. Exact positioning is not critical since the actual distance from the instrument to the TBM will be measured. The RP places the range pole next to the TBM and extends the level rod as needed. An additional range pole can be placed at the profile monument if needed to better define the profile azimuth.

After the instrument is leveled, a backsight (BS) reading of the level rod on the TBM is taken and the instrument height (HI) is computed. This computation is necessary to determine if turning points (TP) are required and at what relative elevation the survey datum (mean sea level, mean low water, etc.) will be reached. The distance from the TBM to the instrument is then measured using the level rod.

The instrument should be checked frequently during the survey to ensure that it remains level. If the instrument becomes out of level, it must be re-leveled immediately and a notation made in the fieldbook. After the profile is completed, a new backsight reading must be taken to establish the height of the instrument for that section of the profile surveyed after the instrument was releveled. If the point at which the instrument was determined to be out of alinement is unknown, then the profile must be resurveyed.

2. Survey Line.

The profile is surveyed to the survey datum (or farther) with elevation and stadia readings taken at every change in slope or every 30 to 50 feet or 9.1 to 15 meters (15 to 20 paces). Since the RP selects the points (stations) which define the profile, it is important that the points be carefully chosen (particularly in the dune area) to obtain an accurate cross section of the beach. Points at the high water line and at the edge of the swash zone should be taken and noted. As a check on the stadia measurement, the distance between successive stations on the beach face should be paced by the RP. At each station, the RP should:

- (a) Signal the number of paces using the hand signals given in Table;

- (b) move to an online position, as determined by the instrument and range poles;

- (c) stand facing the IP with rod held vertically (as determined by the circular rod level) until the IP signals either completion of the station data or of the profile survey; and

- (d) on stations closer than 20 feet (6 meters) to the instrument, the level rod should be used as a tape to measure the distance directly.

3. Turning Point (TP).

During a survey, the instrument may have to be moved to another point on the profile line when:











- (a) A change in elevation is greater than the full length of the level rod;

- (b) the distance surveyed is greater than 250 to 300 feet (80 to 90 meters), the limit for accurately reading the stadia distance;

- (c) high wind conditions cause the upper section of the rod to bend, reducing the accuracy of the readings; and








- (d) the Sun is behind the rod making the numbers difficult to read.

Table. Surveying hand signals.

Rod person (RP)	
Pace count (No.)	Signal
<u>Level rod in left hand</u>	
0	Right hand describes a "0" 
1	Right arm straight down 
2	Right arm at 45° to legs 
3	Right arm straight out to side 
4	Right arm at 45° to head 
5	Right arm straight up 
<u>Level rod in right hand</u>	
6	Left arm straight up 
7	Left arm at 45° to head 
8	Left arm straight out to side 
9	Left arm at 45° to legs 

Example: To signal a pace count of 15, the RP signals a number "1" followed by a "5."



Instrument person (IP)	
Signal	Procedure
To extend the level rod	Hold arms out horizontally and bring together over head 
Rotate rod to show numbers	Right hand describes a small vertical circle, then points in direction movement is needed 
Survey point completed	Move right hand out from shoulder 
Profile line completed	Wave both arms above head 
Sand sample location	Point twice at ground 
Plumb rod	Hold arm up straight and move in direction rod needs to move to make vertical 
Move right or left	Hold arm straight out in direction RP is to move 

The instrument is moved by first reading the elevation and distance to a point on the profile line, and then using this point as a new TBM for establishing the instrument at another position on the profile line. A stake or piece of wood makes a good turning point, and even the bottom of the level rod foot can be used if the rod is not moved during the turning process. After the profile survey is completed, it is necessary to "close" the survey by using a turning point to carry the distance and elevation back to the original TBM. If time permits, turning point calculations should be made before leaving the profile line. If an error is found the line should be resurveyed. Even if turning points are not used, a final reading of the elevation of the TBM should be made to check the HI and close the survey.

4. Surf Zone.

To properly compare successive surveys of a profile line, it is important that each survey extends to a consistent elevation, usually the survey datum. Although surveys should be planned for low tide, surf-zone surveying is usually required (Fig. 4). Surf-zone surveying is difficult because (a) the level rod is often fully extended making it susceptible to movement by waves and wind, and (b) it usually requires reading the smaller numbers on the upper sections of the rod. Depending on the wind and wave conditions, the following procedures are given:

(a) Low wind and wave conditions. The RP simply continues the survey to the datum intercept.

(b) Moderate wind or wave conditions. During these conditions, the datum intercept is relatively easy to reach but wind or wave action prevents accurate stadia readings. The IP first turns the instrument onto the beach near the RP and calculates a new HI. This movement alone may make the stadia easier to read; if not, a tape can be used to measure distance into the water. The end of the tape is secured on the RP's wrist and the tape reel is pinned into the beach under the instrument. At each station, the IP first reads the elevation, then pulls the tape taut to read the distance. Note that all distances are still relative to the instrument position.

Surf-zone surveying should be avoided during high wave conditions. If the datum intercept cannot be reached, it can be extrapolated if the final two survey points are close together and are along the straight part of the fore-shore (Fig. 3).

5. Field Notes.

The range, elevation, and the datum of each profile monument and TBM should be recorded in a fieldbook before entering the field. Figure 5 shows a sample page from a profile line survey recorded in the field, with appropriate column headings filled in. The "range" column is used for actual distance measurements of each survey point relative to the profile monument. Each stadia reading, along with measured distances, is entered under the "stadia" column. Note that these readings are relative to the instrument location, not to the profile monument or TBM. Survey points or stations (STA) are numbered in the first column. All readings should be to the one-hundredth place when using a level rod graduated in feet or to the nearest centimeter when using a metric rod.



Figure 4. Surf-zone surveying.

PROFILE 4		FAVORITE BEACH			SMITH X DOE	WIND IS NE
STA.	BS	ELEV.	FS	RANGE	STADIA	4 PICTURES, ROLL 2
TBM	4.35	16.57		84.0	-9'	
1	HI		4.15			
INSTRUMENT LOCATION → 2	20.92		3.35		0	
3			1.35		9'	
4			8.03		20.3	
5			12.66		12.86	
TURNING POINT TP 6		6.49	14.43		15.00	
					13.86	
	2.53				2.88	
	HI				2.18	
SECOND SETUP → 7	9.02		3.98		0	
8			3.02		24.2	
9			4.15		24.7	
10			6.32		6.52	
					6.12	
11			5.98		6.32	
					5.64	
ONLY GROUND ELEVATION POINTS ARE NUMBERED 12			7.32		7.81	
					6.83	
13			9.14		9.85	
					8.43	
TBM			4.35		ck.	

PAGES ← PREPRINTED LABELS	
24	2x2 STAKE TOP
	2x2 STAKE GROUND
	INST. STAKE (A)
	DUNE CREST
7	PACE COUNT
24	(B) SAND SAMPLE LABEL
24	HIGH WATER LINE
8	(C) BERM CREST
	SCARP
5	
STADIA MEASUREMENTS	
10	LOWER BERM CREST
10	(D) SWASH
14	IN WATER
* DIRECT MEASURE FROM INSTRUMENT	
MEASUREMENTS IN FEET	

Figure 5. Sample of field note format for survey starting at temporary bench mark.

As each station is recorded, the readings should be mentally checked by comparing the last place of the three measurements to determine if the difference between the upper stadia reading and the elevation is the same as the difference between the elevation and the lower stadia. If a difference exists, the readings should be rechecked. The importance of this check cannot be over-emphasized, for it significantly reduces rod-reading errors and is a key to accurate stadia surveying. When stadia are used in the surf zone, it may be necessary to read all three measurements during one look through the instrument. This can be done by first calling (out loud) the decimal places of the three measurements, recording and checking them, and then taking a second look to determine the whole number part of each measurement. This procedure can be accomplished easily after a little practice.

When the data are reduced, the rest of the fieldbook should be completed as shown in Figure 6. Each set of readings should be rechecked (using the check described) and errors noted. One unique advantage of the system is the built-in redundancy of the data. If only one of the three readings is in error, it can usually be corrected by using the other two readings and the pace count. A programable calculator or computer program to automatically check and reduce the data is recommended.

FAVORITE BEACH						SMITH X DOE O		WIND IS NE	
PROFILE	4	DATE 25 OCT 80 TIME 1520						4 PICTURES, ROLL 2	
STA.	BS	ELEV.	FS	RANGE	STADIA	PACES			
TBM	4.35	16.57		84.0	-9'			2x2 STAKE TOP	
1	HI	16.77	4.15	84.0				2x2 STAKE GROUND	
2	20.92	17.57	3.35	93.0	0			INST. STAKE (A)	
3		19.57	1.35		9'			DUNE CREST	
4		12.89	8.03	113.3	20.3'				
5		8.26	12.66	134.2	12.86				
IP 6		6.49	14.43	208.2	15.00	24		(B)	
					13.86				
	2.53				2.88				
	HI				2.18				
7	7.02	5.04	3.98	279.4	0	24		HIGH WATER LINE	
8		6.00	3.02	303.6	24.2'	18		(C) BERM CREST	
9		4.87	4.15	304.1	24.7'			SCARP	
10		2.70	6.32	320.6	6.52	5			
					6.12				
11		3.04	5.98	348.6	6.32	10		LOWER BERM CREST	
					5.64				
12		1.70	7.32	378.6	7.81	10		(D) SWASH	
					6.83				
13		-0.12	9.14	422.6	9.85	14		IN WATER	
					8.43				
TBM		16.57	4.35		OK				
MEASUREMENTS IN FEET									

Figure 6. Sample of reduced field notes.

V. ACCURACY

The accuracy of any surveying method is highly dependent on many factors, including weather conditions, Sun angle, fatigue, and the experience and care of the IP and RP. The effect of errors also varies depending on the type and magnitude of the error and on the analysis being performed.

Assuming that the instrument is properly aligned and level and that the level rod is plumb, the elevation accuracy of a survey point using the stadia method is equal to the accuracy to which the level rod is read. Distance accuracy is dependent on the accuracy of the rod readings, with the distance computed as

$$D = K_1 \times (US-LS) + K_2 \quad (1)$$

where

D = distance

US and LS = upper and lower stadia readings, respectively

K₁ = stadia multiplier (usually K₁ = 100)

K₂ = focal length constant which varies with the instrument

Equation (1) shows that to obtain distance to the nearest 0.1 foot, each stadia reading must be made to the one-thousandth place. Generally, accuracies to the nearest 1.0 foot are acceptable, but rod readings to the nearest 0.01 foot are required.

Since stadia surveys require three times the number of rod readings as in a level and tape survey, rod-reading errors should be anticipated. Rod-reading errors can be virtually eliminated by performing the mental check previously described. If the rod is plumb, and careful readings are made, then

$$US-E = E-LS \quad (2)$$

where E is the elevation reading, and

$$US-2E + LS = \epsilon = 0 \quad (3)$$

If $\epsilon \neq 0$, then the value of ϵ provides some measure of the quality of the stadia readings for a single survey point. Although an ϵ equal to zero is desired, on long shots an ϵ equal to 0.015 unit is generally acceptable. The effect of conducting the mental check is dramatic--of 500 points surveyed with or without the check, the number of points with unacceptable values of ϵ dropped from 14.4 to 2.9 percent. Interestingly, most of the 2.9 percent were for points with an $\epsilon \geq 0.10$. Errors of this magnitude indicate distance errors equal to or greater than 10 feet; however, they are easily corrected by estimating the true distance using the pace count.

During repetitive surveys of the same profile, the stadia method showed acceptable repeatability and an ability to measure profile volume to an accuracy of ± 0.5 cubic yard per foot (± 1.25 cubic meters per meter), though this value is dependent on profile length.

VI. SUMMARY

A method for efficient two-person stadia surveying has been described. Using these procedures, a survey of a single beach profile line can be completed in approximately 15 to 20 minutes, including instrument setup. A high degree of accuracy can be maintained if:

(a) The profile line is monumented (discussed in Sec. III) so that stadia are not used to establish the location of the instrument;

(b) a mental check is made of the one-hundreth place of each rod reading as discussed in Section IV, 5;

(c) a record is made of the number of paces walked by the rod person between each survey point; and

(d) the check discussed in Section IV, 5 is repeated as an additional check on the reduced data. Any errors should be checked using the pace count.

The stadia survey should not replace the standard rod and tape beach surveying; however, it is superior to the Emery method and should be considered when only two people are available.

<p>Birkemeier, William A. Fast, accurate two-person beach surveys / by William A. Birkemeier. --Fort Belvoir, Va. : U.S. Army, Corps of Engineers, Coastal Engineering Research Center ; Springfield, Va. : available from NTIS, 1981. [17] p. : ill. ; 27 cm.--(Coastal engineering technical aid ; no. 81-11) Cover title. "August 1981." Includes bibliographical references. Report discusses a modified stadia (two person) beach surveying method, developed and field tested during 3 years of studying winter storm effects. Modifications include the addition of two stakes to the profile line monumentation, pacing the distance between each point, and performing a simple mental field check of data quality. A typical profile of 10 to 15 survey points can be surveyed in 15 to 20 minutes including instrument setup time. 1. Surveying. 2. Beaches. I. Title. II. Series. TC203 .U581ta no. 81-11 627</p>	<p>Birkemeier, William A. Fast, accurate two-person beach surveys / by William A. Birkemeier. --Fort Belvoir, Va. : U.S. Army, Corps of Engineers, Coastal Engineering Research Center ; Springfield, Va. : available from NTIS, 1981. [17] p. : ill. ; 27 cm.--(Coastal engineering technical aid ; no. 81-11) Cover title. "August 1981." Includes bibliographical references. Report discusses a modified stadia (two person) beach surveying method, developed and field tested during 3 years of studying winter storm effects. Modifications include the addition of two stakes to the profile line monumentation, pacing the distance between each point, and performing a simple mental field check of data quality. A typical profile of 10 to 15 survey points can be surveyed in 15 to 20 minutes including instrument setup time. 1. Surveying. 2. Beaches. I. Title. II. Series. TC203 .U581ta no. 81-11 627</p>
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